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Final Technical Report

NASA HET-DAP Award: NEUTRON STAR POPULATIONS IN X-RAYS and γ-RAYS
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The proposed goal of this High Energy Theory/ Data Analysis Program grant was the study of neutron stars' emission in X-rays and γ-rays and their resulting appearance as galactic source populations. A number of significant new results were obtained in this investigation; in part these have been reported in the papers described briefly below. Certain associated projects obtained additional support from private foundation grants and individual mission AOs for specific new data sets. Some facets of this investigation are continuing under the LTSA program. However, these HET/DAP funds have formed the core support for the PIs compact object investigations; it is appropriate to report here on the program results.

In one of the main efforts of this proposal, substantial progress was made on the development of a new model for the emission of γ-rays from isolated rotation-powered pulsars. In phase 1) of the work (Chiang and Romani 1994, following Chiang and Romani 1992), we showed how a modified version of the 'outer gap' model of pulsar emission could reproduced the double peaked profiles seen in *CGRO* pulsar observations. This work also demonstrated the the spectrum of gap radiation varies significantly with position in the magnetosphere, and produced approximate computations of the emission from outer magnetosphere gap zones, including primary curvature radiation, $\gamma-\gamma$ pair production and synchrotron radiation and inverse Compton scattering by the resulting secondary particles. One main conclusion of Chiang and Romani (1994) was that the original Cheng, Ho and Ruderman (1986) picture of outer magnetosphere radiation physics could not reproduce the fluxes seen from newly observed γ-ray pulsars.

Recently we further developed our new magnetosphere model with a more complete treatment of the geometry of the radiation zone, and improved connections with observations at other wavelengths. In Romani and Yadigaroglu (1995) we computed high energy pulse properties individual pulsars, producing detailed profiles, radio-gamma ray pulse lags and polarization properties in good agreement with the data. In Yadigaroglu and Romani (1995a) we estimated the evolution of γ-ray luminosity with pulsar age and developed a population synthesis model for comparison with known pulsars and the EGRET galactic plane sources. One useful product of this effort was a series of high quality video animations of the complex geometry of this model (for samples see http://astro.stanford.edu/home/ion; see Yadigaroglu (1995) for a popular description of this pulsar program). The population work is presently being extended (Yadigaroglu and Romani 1996) with a more detailed population synthesis, based on physical models for the γ-ray emissivity. This work also 'identifies' many of the un-ID'ed EGRET plane sources, developing a new search strategy that allows positive association with young stellar objects and their products; this work provides important new insights into the Galactic plane population and the birth properties of young neutron stars.

Other work on the high energy pulsar emission has examined the possibility of MeV-GeV polarization measurements (Yadigaroglu and Romani 1995b) and has developed a new picture of radiation physics and particle acceleration in neutron star magnetospheres (Romani 1996). This scheme of radiation in the outer magnetosphere has now been sufficiently developed to provide a substantial new model for pulsar emissions above the radio band. We are now turning to more detailed pulse profile and spectrum computations and to comparison with specific archival and new space-based observations. These new efforts have been reported in recent conferences; new data analyses and publications are in preparation. One PhD thesis (J. Chiang) has resulted in a large part from this work; a second (I.-A. Yadigaroglu) is expected in the next year based on the pulsar results.

A second major thrust of the neutron star modeling efforts has been a new theoretical study of neutron star atmospheres and models of their thermal surface emission. In Romani *et. al.* (1995) we reported on a series of model atmospheres based on new opacity data from the OPAL group. A complete description of this new family of models for low field neutron stars with various surface compositions was reported in Rajagopal and Romani (1995). There we also compared with X-ray observations of the millisecond pulsar J0437-4715; this work has afforded the first observational constraints on the chemical composition of the neutron star surface. A major extension to this effort is now nearing completion (Rajagopal, Romani and Miller 1996). In this program we are using models for atoms in high fields to compute photon cross sections and opacities for iron in $> 10^{12}$G fields. This is a major computational effort, requiring careful approximations of a wide range of physical processes in dense, high B material. This work is being completed with radiative transfer of the polarized X-ray flux through the neutron star atmosphere, and should result in the first reliable neutron star spectra for young pulsars with heavy element surfaces. The results will be compared with ROSAT and ASCA data.

During this proposal there have also been studies of BH LMXB populations (Romani 1994, 1995a), the evolution of neutron star magnetic fields (Romani 1995b) and the properties of pulsar shock waves and other plerionic emission (*e.g.* Romani, Gilroy and Cordes 1993, Cordes, Romani and Lundgren 1993). This grant support has made possible the attendance of the PI and associated students at four AAS meetings and several other scientific meetings. In addition to conference proceedings reports from talks at these meetings (not listed), the research completed under this program has been described at a number of departmental seminars and popular talks. HET/DAP funds have also been used to maintain the groups computer facilities and to assist in scientific communications.

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